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Positive and negative emotion induction through avatars and its impact on reasoning performance: cardiovascular and pupillary correlates

Mickaël Causse ^{1,3}, Bernard Pavard ⁴, Jean-Michel Sénard ⁵, Jean-François Démonet ^{1,2}, Josette Pastor ^{1,2}

1. INSERM, U825, Toulouse, F-31000 France;
2. Université Toulouse III Paul Sabatier, Toulouse, F-31000 France;
3. Currently at DMIA, ISAE
4. IRIT, UMR 5505 CNRS, INPT & UPS, F-31000 France;
5. INSERM, U858, CHU Rangueil, F-31400 France

Summary

Many studies have shown the impact of emotion on cognition (A. Damasio, 1994), however these influences remain ambiguous. The contradictions may be explained by a lack of experimental control (emotional induction, objective clues on emotional states...) but also by the existence of complex cross-influences between the dorsolateral prefrontal cortex, a major substratum of executive functions (EFs) and the ventromedial prefrontal cortex, an area strongly connected to the limbic system. This work aimed at gaining a more precise view of the links between emotion and EFs thanks to an experimental protocol that used avatars for a well controlled emotional induction, measurements of the autonomic nervous system activity as evidence of the emotional state (cardiovascular and pupillary responses) and a neuropsychological test battery (dynamic reasoning and deductive reasoning tasks) for the detection of EFs variations in response to emotion. The experimental data showed that positive emotion (joy) led to a performance decrease during both tasks, together with physiological variations. These counterintuitive results showed that positive mood can impair executive functioning in our tasks. In addition, our results highlighted the lack of learning effects on deductive performance.

Keywords: *emotion, avatars, executive functions, cardiovascular activity, pupil diameter*

Please address all correspondence to Dr Mickaël Causse, Institut Supérieur de l'Aéronautique et de l'Espace, Centre aéronautique et spatial, 10 avenue Édouard Belin BP 54032 - 31055 TOULOUSE Cedex 4;
e-mail: mickael.causse@isae.fr

Introduction

Ekman (1984) has established a list of six primary emotions: joy, anger, disgust, fear, sorrow and surprise. Two dimensions have been also identified: valence and activation. While the dimension of valence refers to the positive/negative aspect of emotion (joy is the only primary emotion with positive valence), the dimension of activation concerns its intensity. Valence and activation have received a significant number of experimental validations, in particular through works highlighting their associations with various physiological indicators (Bradley, Cuthbert, & Lang, 1996; Lane, et al., 1997). After Damasio's study (1994) that highlighted the influence of emotion on decision making and that putted forward the somatic markers hypothesis, many researchers have suggested the existence of reciprocal influences between emotion and cognition. For instance, Ashby et al. (2002) have shown the deleterious impact of emotion on working memory. However, the nature of these links remains ambiguous: positive emotion can play a facilitating or a disturbing role (Phillips, Bull, Adams, & Fraser, 2002) and negative emotion may improve (Van Strien, Stolk, & Zuiker, 1995) or degrade (Hogan, 2003) cognitive processes. These contradictions may have three main explanations.

Firstly, during experiments, the nature of the conditioning is not always well controlled in terms of valence and activation. To circumvent this issue, virtual reality can be used. It allows flexibility and precision in emotional stimulation. Facial expressions of the avatars can be generated thanks to numerical values which allow a very precise control of both valence and activation of the emotional stimuli. In a similar way, oral expression, prosody or the intensity of the voice can be adjusted accurately.

Secondly, in some studies no real evidences of an emotional state variation, for example through autonomic nervous system (ANS) measurement (Causse, Sénard, Démonet, & Pastor, 2010), are provided. Three physiological parameters are classically recorded as emotional markers: skin conductance response (SCR), cardiovascular activity and pupillometry.

SCR reflects the electrical variations linked with the eccrine sweat glands activity that is dependant of the excitation of the ANS. The amplitude of the SCR is considered as non-specific to the emotional valence

(Codispoti, Bradley, & Lang, 2001; Greenwald, Cook, & Lang, 1989). The SCR variations reflect the emotional arousal (Dehais, Sisbot, Alami, & Causse, 2011) as well as attentional processing. Moreover, the SCR is affected by various factors such as temperature or food.

Cardiovascular activity reflects emotion since it depends on the relative influences of the two branches of the ANS (Venables, 1991) that perform a complex regulation. It does not have a linear behavior regarding to the emotional activation and seems to be influenced by the emotional valence (Lang, Davis, & Öhman, 2000). Another possible cardiovascular measurement is blood pressure. The diastolic pressure is the lowest pressure at the resting phase of the cardiac cycle whereas the systolic pressure is defined as the peak pressure in the arteries during the cardiac cycle. Systolic pressure and/or heart rate are affected by stress or emotion (Causse, Baracat, Pastor, & Dehais, 2011; Causse, et al., 2010). For instance, Sinha et al. (1992) showed that the systolic pressure and the heart rate increased during fear and anger. Other studies demonstrated that the blood pressure can increase in both presences of positive and negative stimuli (Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 1993; Warner & Strowman, 1995).

Eventually, pupillometry also reflects the activity of the two branches of the ANS and gives clues on emotional state or mental workload (Hyönä, Tammola, & Alaja, 1995). The links between pupillary diameter and emotional state are not yet clearly established. It seems to reflect the emotional activation, the diameter evolving linearly according to the increased arousal (Janisse, 1974). Although Janisse's theory is currently privileged, authors suggested that pupil size may vary on a continuum according to emotional valence: an extreme dilatation for pleasant stimuli and an extreme contraction for aversive stimuli (Hess, 1972).

Thirdly, the nature of the cross-influences between the dorsolateral prefrontal cortex (DLPFC), a major substratum of the executive functions (EFs), and the ventromedial prefrontal cortex (VMPFC), belonging to the "emotional cerebral system", are very complex and may explain apparently contradictory emotional effects on cognition (Simpson, Snyder, Gusnard, & Raichle, 2001). The cerebral structures that are currently identified as being involved in emotional processes represent, beyond the limbic system (Maclean, 1955), a vast cortico-subcortical circuitry (Heimer & Van Hoesen, 2006). While VMPFC lesions cause emotional

impairment, lesions of the DLPFC are associated with EFs disorders. EFs are closed to the central executive of the Baddeley's working memory model (A. D. Baddeley & Hitch, 1974) and allow reasoning, flexible goal-directed behavior, inhibition of dominant responses, updating in working memory or decision making (Godefroy, 2003). Given the complex circuitry of emotion and the cross-influences between DLPFC and VMPFC under emotional factor, EFs assessment represents a good indicator of the emotional impact on cognition.

The work presented hereafter mainly aims at assessing, during a well controlled experimental protocol, the effect of both positive and negative emotions on EFs. The three components of the experimental protocol are:

- The emotional conditioning through virtual avatars to control precisely the emotional conditioning in terms of valence and activation;
- The measurement of the ANS activity through cardiac activity and pupillary response to get evidences on the emotional state variations;
- The test battery that addresses two aspects of reasoning: reasoning in dynamic situations, which has proven to involve massively EFs and deductive reasoning, which is the core of high-level cognition.

Our work is based on two main hypotheses: 1) Emotional induction thanks to the virtual avatars will affect the executive performance; 2) Executive performance variations will be related to emotional induction and this will be ascertained through cardiovascular and pupillary responses.

Methods

Participants

Healthy participants ($n = 12$) were recruited by local advertisement. Inclusion criteria were: young male (18-30 years old), native French speakers, right-handed (as measured by the Edinburgh handedness inventory, Oldfield, 1971), under or postgraduates. We excluded participants with sensorial deficits, history of mental retardation, neurological/psychiatric disorders or emotional disorders. All participants received complete information on the study's goal and experimental conditions and signed an informed consent. Participants were randomly assigned in two separate groups: six participants received emotional conditioning during the deductive task, and the other six during the dynamic one.

Executive Function Tests Battery

We have selected three neuropsychological tasks: a dynamic reasoning task involving planning and working memory abilities, a task involving deductive reasoning and a control task to check the homogeneity of between-group performance in terms of visuo-motor abilities.

The dynamic reasoning task: it assesses reasoning under temporal pressure (Pastor, Agniel, & Celsis, 1998). The objective is to control a network of tanks and pipes (Figure 1) where water flows by gravity, according to the laws of hydraulics. The capacities of the top and bottom tanks are equal to the total amount of water running in the network. At the beginning of the task, all tanks, except the top one, are empty. The instruction is “to fill the bottom tank as quick as possible by acting on on/off valves and avoid as much as possible overflowing the intermediate tanks”. The performance measures were the mean percentage of water loss and the mean number of actions on valves.

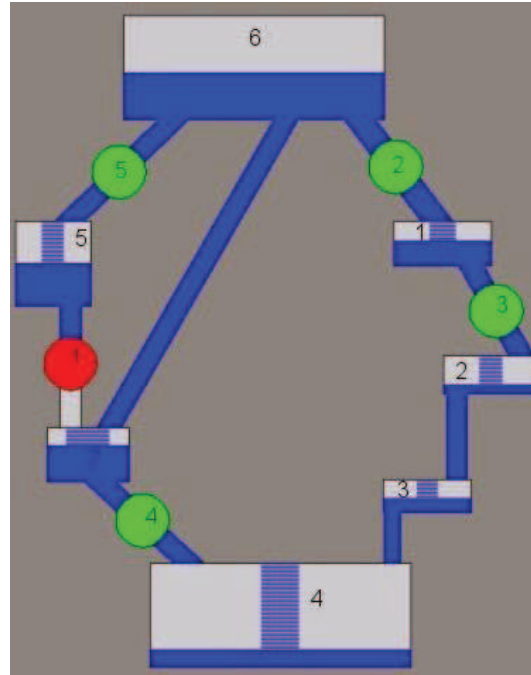


Figure 1: The dynamic task. The valves appear in green when they are open and in red when they are closed.

The deductive reasoning task: it is inspired from Natsopoulos et al. (1997). Current researches underline the fact that normal adults do not spontaneously apply the principles of logic (Evans, 2003). The goal of the task is to solve syllogisms by choosing, among three suggested solutions, the one that allows concluding logically. The syllogisms (Figure 2) are based on a logical argument in which one proposition (the conclusion) is inferred from a rule and another proposition (the premise). We used the four existing forms of syllogisms: “modus ponendo ponens”, “modus tollendo tollens”, “fallacies of the affirming the consequent” and “fallacies of denying the antecedent”. The syllogisms’ sentences varied in terms of length and semantics. The purpose was to avoid contextual effects which could help or perturb the deduction and thus, to force a purely logical reasoning. Each participant had to solve 24 randomly displayed syllogisms. The measurement was the mean percentage of correct responses.

- If Gao Xingjian has written “The storm”, then Gao Xingjian is not a good writer.
- Gao Xingjian has not written “The storm”
- 1) I cannot say anything on his writing abilities
- 2) Gao Xingjian is not a good writer
- 3) Gao Xingjian is a good writer

Figure 2: A syllogism example (translation from French).

The target-hitting task: it assesses basic visuo-motor abilities. The participants had to click as quickly as possible on a target that appeared successively at random positions on the screen. The measurement was a velocity index. Emotional conditioning was not administered during this task that was only intended to check between-group homogeneity in terms of visuo-motor performance.

Emotional avatars

Participants were emotionally conditioned by avatars created with Poser 6.0 (© Curious Labs). Avatars' brightness (moderate in order not to bias the pupil size measurements) and sex (male, for a weakened interaction with the participants' emotional status (Ku, et al., 2005)) were controlled. Avatars expressed their emotion through facial expressions (Figure 3). Their comments were always semantically neutral and emotion rose from tone of speech and prosody. For instance, avatars comments were (translation from French): *“Listen, this is a task that normally presents no problem, you should not have any – is seems to me – so just be careful, just be careful”*. Joy is the only basic emotion with a positive valence and a study of Adolphs 2002 showed that anger yields a similar level of activation as joy does. For instance, the emotions fear and surprise generate a higher level of activation than anger and joy do. Upon this basis, the different tested emotions were joy (positive valence) and anger (negative valence) plus a neutral emotion as a control condition. Each commentary, although semantically neutral, had interpretations in the three emotional valences. In order to be the most realistic possible, facial expressions, gestures, comments and labial movements of the avatars were copied on a non-professional actor, who previously played the scenes.

Preliminary tests allowed us to select the avatars for which emotion was correctly recognized with an error rate of less than 5%.

During the dynamic task, the avatars appeared at critical moments at the periphery of the screen. During the deductive task, avatars were displayed in full screen between two syllogisms. The avatars were presented four times with the same valence of emotion during a same task to try to maintain a continuous emotional state. For each emotional valence, two different types of avatars were alternatively displayed two times along the task. Although the avatars' comments had no link with the participants' performance, the facial expressions and the prosody of the speech were strong enough to make the participants think that the avatars were judging their performance. The order in which the different types of avatars were displayed was counterbalanced across the participants and across the tasks to avoid order effects.



Figure 3: Illustration of the three different types of expressed emotions, neutral, joy and anger.

Procedure

The total test battery performance lasted approximately one hour. The experimentation took place in a calm office within the Centre for Clinical Investigation (Toulouse, France). Each participant specified his age, laterality and confirmed the absence of medication or other disorders. The different tasks were

performed on a Sony Vaio PCG-GRT816M laptop. Participants used the mouse or a Cedrus (Model RB-730) response pad to accomplish the task. All the participants performed two different blocks of tasks (Figure 4). In the first block (in white), each participants performed the three control tasks (dynamic task, deductive task and target hitting task with no emotional conditioning) In the second block (in grey), each participant performed three times the same task according to the three emotions: for the first group of participants this “tested task” is the dynamic one, for the second group of participants this is the deductive one. For example, participant 1, who belonged to the group emotionally conditioned during the dynamic task, performed this task without emotion, and then he performed the target hitting task and the dynamic task (white bloc). Finally, the participant performed three times the deductive task with positive, negative and neutral conditioning (in grey). To cope with learning effect, all the tasks were counterbalanced across subjects. Each participant began the experiment by the task that will be submitted to emotional induction later in the grey block.

<i>S1</i>	<i>S2</i>	<i>S3</i>	<i>S4</i>	<i>S5</i>	<i>S6</i>	<i>S7</i>	<i>S8</i>	<i>S9</i>	<i>S10</i>	<i>S11</i>	<i>S12</i>
Dy	Dy	Dy	Dy	Dy	Dy	De	De	De	De	De	De
T	T	T	De	De	De	T	T	T	Dy	Dy	Dy
De	De	De	T	T	T	Dy	Dy	Dy	T	T	T
Dy +	Dy +	Dy -	Dy -	Dy 0	Dy 0	De +	De +	De -	De -	De 0	De 0
Dy -	Dy 0	Dy 0	Dy +	Dy -	Dy +	De -	De 0	De 0	De +	De -	De +
Dy 0	Dy -	Dy +	Dy 0	Dy +	Dy -	De 0	De -	De +	De 0	De +	De -

Figure 4: Experimental design. Si = participant number; De = deductive task; Dy = dynamic task; T = target-hitting task. +, -, 0 are respectively positive, negative and neutral emotional valences.

ANS measurements

The participants were comfortably installed during 4-5 minutes so that the physiological parameters came back to a rest state. Indeed, experimental context may create a stress that bias ANS measurements. A headphone was placed on the ears of the participants for a better isolation from disturbing noises and to transmit the comments of the avatars.

Although SCR is widely used in studies on emotion, its insensitivity to the valence of emotion and its dependency on non emotional, non controllable parameters constitute major drawbacks that prevented its

use in our experiment. On this basis, we choose to measure cardiovascular activity and pupillary responses. All physiological measurements were synchronized with tasks thanks to triggers. The cardiovascular parameters were recorded with a Finapres sensor plugged to an electrocardiogram (Ohmeda 2300). The Finapres is a non-invasive continuous blood pressure monitor, based on the vascular unloading technique. The Finapres sensor was placed on the middle finger of the left hand and recorded the heart rate and the blood pressure. Pupillometry was collected thanks to the iView X RED eyetracker (SensoMotoric Instruments, Teltow, Germany). The main interest of this type of oculometer (remote camera) is that it is non-invasive, which allows a more ecological situation. In practice, establishing mean physiological values for a group of participants for an entire task is meaningless because of inter-individual variability. As a consequence we computed delta values (difference between working and resting states).

Statistics

All behavioral data were analyzed with Statistica 7.1 (© StatSoft). The Kolmogorov-Smirnov goodness-of-fit test has been used for testing normality of our variable distributions. As these latter did not follow a normal distribution, we used non-parametric Friedman's test to examine the main effects of avatars on behavioral and physiological variables. Post-hoc paired comparisons were examined using the Wilcoxon Signed-rank tests

Behavioral results

Target-hitting and control tasks

The velocity index in the target-hitting task and the performance of the control dynamic and control deductive tasks did not differ across the dynamic task group and the deductive task group. In the control deductive task, the mean percentage of incorrect responses was 25% ($SD = 16.87$). It is interesting to note

that the participants of the deductive task group did not improve significantly their percentages of correct responses along the four repetitions of the deductive task.

Attentional vs. emotional effects

The results showed no effect, whether in the dynamic task or in the deductive task, of the display of neutral avatars on the task performance compared to the performance in the control task (no avatar presentation). The effects described hereafter cannot therefore be due to an increased involvement of attention due to the avatars' sudden comments.

Dynamic task, emotional effects

We found an overall significant differences concerning the number of actions (openings and closings) on valves (Figure 5) between the three emotional conditions ($\chi^2(6,2) = 7.00; p = .030$). In particular, paired comparisons showed that there were less actions on valves during the positive condition than during the negative one ($Z = 2.20, p = .027$).

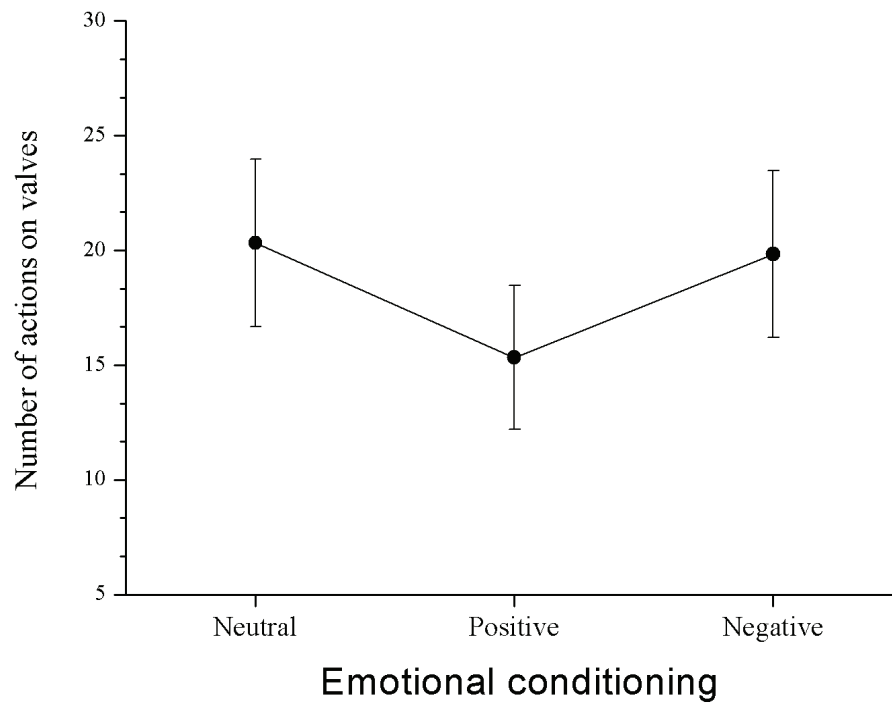


Figure 5: Number of actions on valves during the dynamic task according to each emotional conditioning. Error bars represent the standard error of the mean.

Deductive task, emotional effects

The percentage of correct responses tended to be different (Figure 6) across the different emotional conditions ($\chi^2(6,2) = 5.47; p = .060$). Paired comparisons showed a decline of the correct response rate in positive emotional condition in comparison to neutral one ($Z = 2.02, p = .043$) and a tendency toward a decrease in comparison to the negative one ($Z = 1.88, p = .059$).

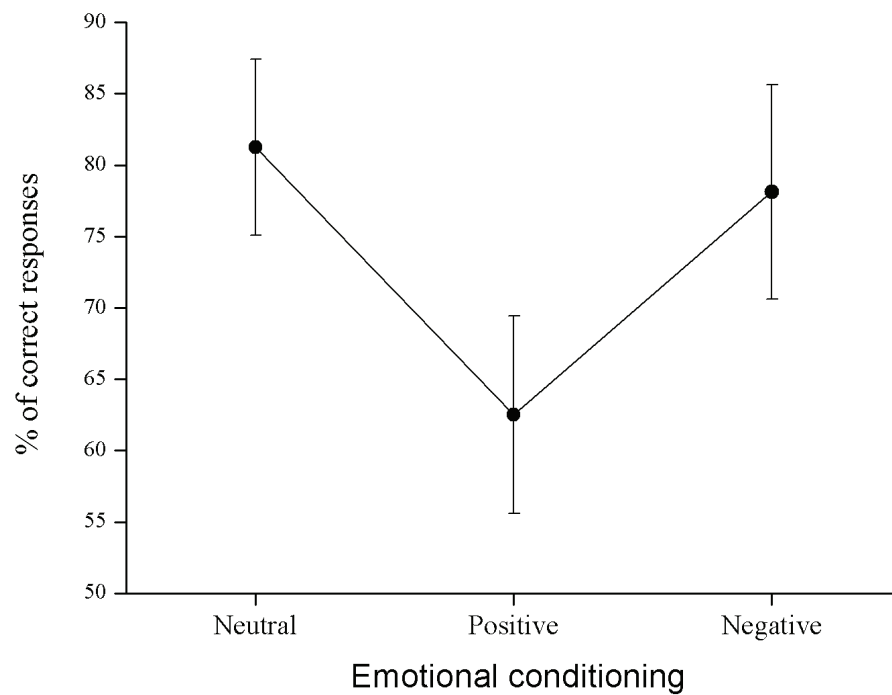


Figure 6: Percentage of correct responses in the deductive task according to each emotional conditioning. Error bars represent the standard error of the mean.

ANS results

Attentional vs. emotional effects

The results showed no effect, whether in the dynamic task or in the deductive task, of the display of the neutral avatars on the ANS activity during the task performance compared to the rest state. This result strengthened the hypothesis that no increased involvement of attention due to the avatars' sudden comments occurred. The mean systolic blood pressure monitored for the dynamic control task was 134.8 mmHg whereas it was of 124.6 mmHg during the deductive control task.

Dynamic task, emotional effects

Results showed no effect of the avatar display on the different cardiovascular variables or on the pupil diameter during the dynamic task performance.

Deductive task, emotional effects

Friedman's test showed that the mean systolic blood pressure differed across the three emotional conditions ($\chi^2(6,2) = 6.50$; $p = .038$), see Figure 7. Paired comparisons revealed a trend of the systolic pressure to be higher during the positive condition in comparison to the neutral and negative ones ($Z = 1.82$, $p = .067$, in both comparisons).

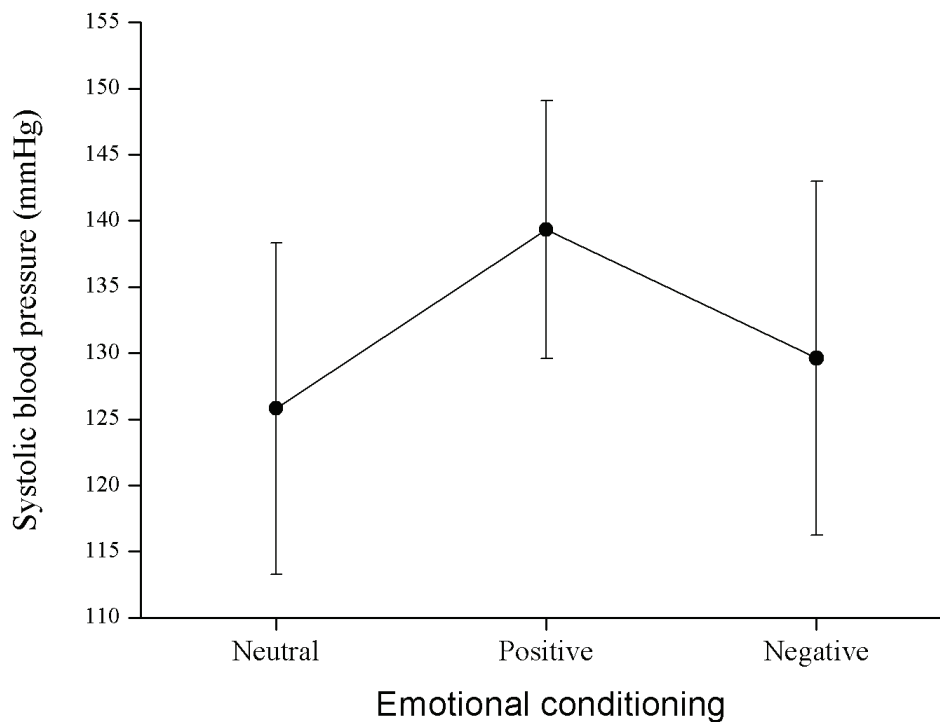


Figure 7: Systolic blood pressure in the deductive task according to each emotional conditioning. Error bars represent the standard error of the mean.

The pupillary response did not varied significantly across the 3 emotional valences ($\chi^2(6,2) = 1.33$; $p = .513$) during tasks time course, see Figure 8. However, post-hoc test showed that there was a trend of the pupil diameter to be larger in the positive condition than in the negative one ($Z = 4.21$, $p = .074$).

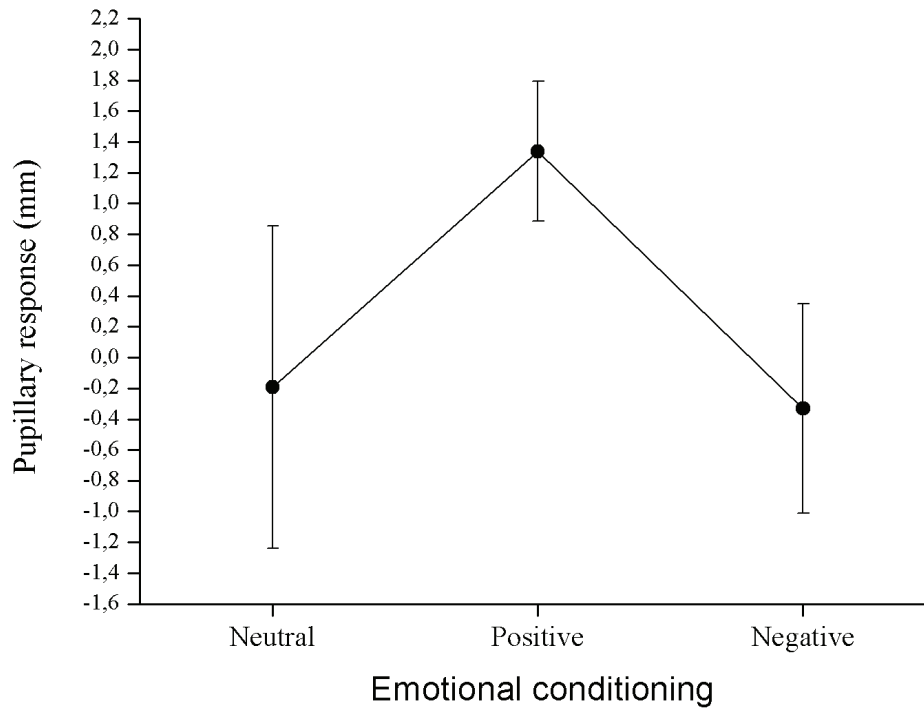


Figure 8: Mean pupillary response in the deductive task according to each emotional conditioning. Error bars represent the standard error of the mean.

Habituation to avatars

We found that the mean pupillary response during the display time of the four avatars (not the mean pupillary response along the whole task time-course as previously) was more important during positive avatars than negative ones, respectively 0.54 mm (SE = 0.44) vs. -0.08 mm (SE = 0.06). In this task, the mean pupillary response differed across the four positive avatar repetitions ($\chi^2(6,3) = 9.40$; $p = .024$). Pupil diameter increased during the two first avatar presentations then came back progressively to its baseline value along the second part of the task. Paired comparisons showed that pupil diameter was higher during

the first presentation of the avatar than during the third and the fourth ones (respectively, $Z = 2.20$, $p = .017$; $Z = 1.99$, $p = .046$) and during the second presentation of the avatar than during the third one ($Z = 1.99$, $p = .046$), see Figure 9. This last result should be considered with caution since the important between-subjects variability during the two first presentations of the avatars.

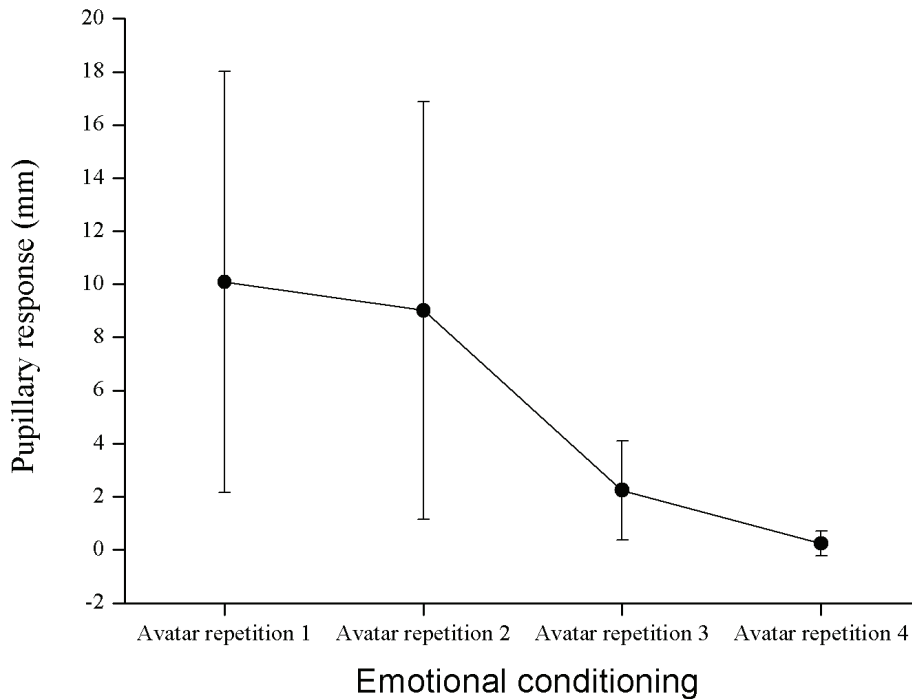


Figure 9: Mean pupillary response across the four repetitions of the positive avatars during the deductive task. Error bars represent the standard error of the mean.

Discussion

Emotional effects on behavior

Our first hypothesis stated that the emotional avatars should affect EFs. Our results showed that positive avatars were deleterious to EFs performance during both dynamic and deductive tasks. In the dynamic task, the positive emotional conditioning generated a significant decrease of the number of actions on valves (openings and closings). The display of the joyful character had probably led the participants to be more

relaxed and they likely demonstrated a lower monitoring effort along the task. Concerning the deductive task, in contradiction with Isen results (2004), analyzes revealed that the positive emotional conditioning provoked a decline of the correct responses rate. Taken together, these results are in agreements with Phillips et al. (2002) who reported a fall of the performance in response to positive emotion induction in the Tower of London task. It is also interesting to note that the mean percentage of incorrect response was important during the control deductive task (25%). This result is in agreement with Braine (1990) and confirmed the lack of natural competence of humans in pure logical reasoning. Coherently, an additional analysis revealed that the participants of the deductive task group did not improve their percentage of correct responses along the four repetitions of the deductive task.

Emotional effects on ANS

Our second hypothesis assumed that the emotional avatars should provoke changes in the ANS activity, providing evidence on the efficiency of avatars to induce an emotional state. The results partially corresponded to this assumption since ANS activity was only impacted by positive avatars during the deductive task.

In agreement with Prkachin (1999), the effects on cardiovascular activity mainly occurred on the systolic blood pressure. When the deductive task was performed under positive emotional conditioning, the systolic blood pressure showed a trend to be higher in comparison to the other emotional conditions. This cardiac variation is coherent with the above behavioral results. We were not able to find ANS changes during the dynamic task. Several explanations can be proposed. Firstly, the dynamic task generated a high psychological stress: the mean systolic blood pressure monitored for the dynamic control task was 134.8 mmHg whereas it was of 124.6 mmHg during the deductive control task. This increase of systolic pressure due to the only effect of the task had probably masked the emotional effects of the avatars. In addition, the strong involving of EFs during this task could have decreased the emotional effect of the avatars, likely reflecting a DLPFC inhibition on the VMPFC. Secondly, whereas avatars were displayed in full screen during the deductive task, they appeared in miniature at the periphery of the screen during the dynamic task.

This choice has been made not to generate visual (not to hide the water level in the tanks) or operational interferences (not to hide the valves). It is likely that the size of avatars was too low for the facial expressions to be clearly perceived and thus to be effective enough to induce an emotion.

Results also showed a trend of the pupil diameter to be larger during the positive emotion than during the negative one. In addition, pupil dilation was more important during the first and the second avatar than during the third and the fourth avatar. During the two last avatars, pupil diameter came back progressively to its baseline value, reflecting a habituation effect. The increase of the pupillary diameter during the two firsts avatars is coherent with the fall of correct responses during the positive emotional condition in the deductive task. As larger dilations and task performance decline occurred within the positive condition only, we may hypothesize that our positive emotional conditioning generated a stronger emotional arousal/activation. Indeed, Janisse (1974) showed that the pupil diameter evolves linearly according to the activation of emotional stimuli, independently of their valences.

Eventually, the analysis showed that the display of the emotionally neutral avatars did not generate behavioral or physiological variations. According to this outcome, we assume that no attentional bias could explain behavioral or physiological variations observed with positive avatars.

Conclusion

We observed the effects of positive emotion on cognitive performance together with changes of the physiological activity. Our results showed that positive mood can impair executive functioning: behavioral changes consisted in a lower monitoring effort along the dynamic task and in a decline of reasoning performance in the deductive task. These variations were not related to attentional effects because neutral avatars did not generate behavioral or ANS modifications. The main limitation of this study concerns the sample size that was quite low and that had probably limited some results to tendencies. A higher number of subjects could have helped us to increase the strength of our conclusions. In addition, the four successive repetitions of the avatars with only two different avatars per emotional valence may have induced a habituation effect, deleterious to emotional induction efficiency. The effect of habituation would probably

have been limited by the introduction of more variability in the avatars' facial expression and comments for a same emotional valence. Eventually, because of the between-subjects variability, it would have been interesting to take into account the emotional profiles of our participants thanks to questionnaires.

According to Ku and et al. (2005), the ability of avatars to transmit and provoke an emotional state remains quite limited. However, this technique provides a very flexible and accurate manipulation of emotional induction with a high fine-tuning of valence and intensity of facial expressions, gesture and prosody. Solutions should be found very soon to increase the avatars effect on mood states, by improving the “sense of presence” in virtual reality (Lee, 2004).

Analyzing the effects of emotion on cognition may lead to applications in Neuropsychology. For example, it could help the assessment and the rehabilitation of patients (Mateer, Sira, & O'Connell, 2005) suffering neurological pathologies where the emotional impairment and the dysexecutive syndrome are closely entangled, such as during the early stages of the Alzheimer's disease. Emotional assessment is also interesting for Neuroergonomics and Human Machine Interaction in the field of complex working situations where emotion may causes accident (e.g. potential source of air crashes, Dehais, Tessier, & Chaudron, 2003).

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